Teaching and Mentoring across Traditional Boundaries: Two Institutions, Three Mentors, 10 Students, and One Global Data Set

PURM
Perspectives on Undergraduate Research & Mentoring

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Natural history museums around the world house an estimated three billion specimens, with nearly one billion in U.S. museums (Network Integrated Biocollections Alliance, 2010). These specimens are a sample of the diversity of life on Earth collected over the past 250 years from all parts of the globe. Researchers have long used specimens and their associated data to investigate a wide variety of questions in the fields of evolution, ecology, species conservation, public health, and others. With the advent of personal computers in the 1980s, museums began the process of digitizing their collections. This process typically includes transcription of specimen data into a computer database, as well as imaging specimens and associated field notes. Many of these specimen records are now publicly available through online data portals and thousands of specimen records can be easily downloaded. Digital collections data provide opportunities for undergraduates to engage in collections-based research regardless of proximity to the collection (Cook et al., 2014; Lacey et al., 2017; Monfils et al., 2017).

Data portals such as the Global Biodiversity Information Facility (www.gbif.org) or Integrated Digitized Biocollections (www.idigbio.org) aggregate information about specimens from around the world, allowing undergraduate research to address questions on an international scale. Natural history collections incorporate specimens collected over centuries, providing a historical perspective to globally relevant research topics, such as the spread of invasive species, species extinctions, conservation planning, and climate change (Graham, Ferrier, Huettman, Moritz, & Peterson, 2004; Shaffer, Fisher, & Davidson, 1998; Ward, 2012). Collections data is also specimen based, with data records tied to physical specimens that can be accessed to collect additional information. With increasing digitization, the online specimen records for some species can be measured in the thousands, providing students with the opportunity to gain experience with large datasets, an increasingly critical skill in scientific research (O'Reilly et al., 2017).

To take advantage of the educational opportunities provided by digitized natural history collections, we formed a teaching collaboration between faculty and curators at two diverse institutions focused on education and research. The combination of a faculty member from the Biology Department at Widener University, a teaching-focused undergraduate program with an emphasis on undergraduate research, and curators from the Delaware Museum of Natural History, home of two of the largest international mollusk and bird collections in North America (Sierwald, Bieler, Shea, & Rosenberg, in press), provided a diverse range of experience and expertise. Together, we developed BIOL388 Natural History Collections, a new course-based research experience (CURE) for junior and senior undergraduates. CUREs can provide many of the same advantages and learning gains as traditional apprentice research experiences and can be effective in increasing participation in undergraduate research (Bangera & Brownell, 2014; Frantz et al., 2017; Shapiro et al., 2015). Our students participated in authentic research experiences incorporating digitized natural history collections, drawing on the expertise of each member of the teaching team. All student research teams used geographically widespread and non-local specimen data with most using international specimen data. Additionally, students collaborated with the museum curators, broadening their perspectives on research communities, opportunities, and careers. We provided students with considerable latitude in choosing and directing their research projects. This necessitated extensive mentoring by both faculty and curator members of the teaching team, which has been identified as a key component in helping undergraduates develop their identities as scientists (Linn, Palmer, Baranger, Gerard, & Stone, 2015). In this paper, we present our experiences as mentors and mentees in this research-based course focused on broadening student experiences and helping to move undergraduates from students to research collaborators.

Teaching Team Perspective

Our teaching collaboration started through a desire to diversify the learning experiences of undergraduate biology students. We accomplished this in two primary ways. First, we exposed students to the diversity of natural history collections, which allows research on biological diversity (squid to sparrows), geographic diversity (specimens collected across the globe), and historical diversity (how biological systems have changed over time). Second, we exposed the students to diverse research environments through interactions with traditional Widener University faculty and curators at the Delaware Museum of Natural History. This combination created a teaching environment that broadened our students' perceptions of the availability of research opportunities on national and international scales. It also created an opportunity for students to engage in research experiences in a museum setting, increasing their awareness of diverse research communities.

In spring semester 2018, ten students completed research projects centered on digitized natural history collections in BIOL388 Natural History Collections at Widener University. None of the students had prior research experience with museum specimens or natural history museum collections. Students spent the first three to four weeks gaining hands-on experience with natural history collections, followed by eleven weeks working on their research projects. Student teams were encouraged to choose their own research questions within pre-selected taxonomic groups (Song Sparrows or freshwater mussels) that aligned with the areas of expertise of the curators. The wide scope of potential projects using digitized natural history collections resulted in the students exploring national and international specimen datasets, where each student team worked with specimens from different non-local geographic areas.

Our students tackled complex global ecological questions, including climate change, invasive species, human impacts on species diversity, and impacts of climate on morphology and life cycles. This was only possible because of the close coordination and collaboration between the students and the teaching team. We wanted to provide our students with a research experience that challenged them to work as collaborators and actively participate in guiding the direction of their project. This required the students to set aside a more passive mindset where they expected the teaching team to provide all the answers and accept the idea that they would create new knowledge through their projects. We accomplished this through research projects that were truly student designed and executed and not vetted in advance by the professor. This type of open-ended project, with students learning not only new content, but also research techniques, required a level of small group mentoring unusual in other courses. With each student team working on different projects, a coordinated teaching team was essential. Our teaching team met weekly outside of class hours to discuss directions, problems, and next steps for each of the student research teams.

The goals of the course challenged the teaching team to adjust their mentoring. Our past experiences with mentoring in a research setting have typically involved single students working on established research projects or in more structured course settings where mentoring is less individualized. In both of these situations, research questions and methods are often already established and the mentor has significant experience with the research system under study. In this class we wanted to provide students the opportunity to lead the research and set the questions to be addressed as this is a key part of any research collaboration and an important part of a successful CURE experience (Auchincloss et al., 2014). Because each student team addressed a different research question, mentoring typically occurred in a small group (e.g., the professor, the curator, and two students). Guiding the transition from a student to a collaborator required mentors to be open to the students' research question ideas and guide but not dictate their path to a project of the appropriate scope for the class. We had to be willing to let them discover for themselves that some questions could not be answered by the available data. We also had to refrain from answering every student question about their research system and instead encourage them to seek answers in the scientific literature or through discussion with their research partner. The students embraced the freedom to choose their own research questions, but we found that their ideas changed from week to week. As mentors, we needed to respect these ideas while also ensuring that students settled on one question in time to complete the research by the end of the course.

Datasets that spanned large geographic areas required our students to consider ecosystem and climate differences across North America. When students conducted research involving nesting locations of Song Sparrows, they were able to download more than 10,000 individual specimen records from the iDigBio online data portal, each one associated with a physical museum specimen that included preserved study skins, skeletons, and eggs. Student researchers had to determine which specimen records were appropriate for their studies, keeping breeding adult specimens and excluding juveniles and adults that might have been migrating at their time of collection. For Song Sparrows, the breeding season differed between specimens collected in southern California and those collected in northern Canada and Alaska. Thus, students were required to integrate knowledge of climate and how it affects life cycle timing to determine which specimens were relevant to their research question. This type of research helped students to reach beyond their local ecosystems and use critical thinking to address biological questions with a more global perspective.

Students with an interest in threatened and endangered species are generally precluded from using them in semester long research projects due to stringent permitting issues. However, using digitized natural history collections, students could work with specimen data regardless of conservation status. Students were also able to work with specimen data from areas highly relevant to their questions. Habitat loss or change leading to biodiversity loss is a worldwide problem. One of the prime examples is in the Duck River watershed of Tennessee, over 800 miles from Widener University. The southeast United States has some of the highest diversity areas of Unionidae freshwater mussel species in the world, and the majority of these species are considered endangered, threatened, or of special concern (Strayer et al., 2004; Williams, Warren Jr., Cummings, Harris, & Neves, 1993). Mentoring a student group interested in these issues meant first teaching about the unusual life cycle of these mussels which spend their larval stage living as a parasite on the gills of a particular host fish before dropping off and maturing into adult mussels that live on the river bottom. Human-made dams can prevent fish movement, limiting access of the mussel larvae to their fish hosts. This can affect the reproduction of the mussels, leading to lower levels of species diversity. Students integrated their knowledge of larval mussel biology and their research on mussel species diversity with historical records of dam building on the Duck River to interpret their results. Additionally, the historical nature of the data, with collection records from the Duck River watershed dated back to 1884, may allow future students to examine how specific dams in the Duck River have affected species diversity over time and contributed to the decline of freshwater mussel species.

Over the course of the semester, student teams showed an increased awareness of the limitations and assumptions associated with data collection and analysis. For all students in the course, this was their first time using presence-only datasets. The specimens included in natural history collections come from many different collectors, with different methodologies associated with their individual research questions and goals. Therefore, while collections data may be able to tell you definitively that a certain organism was collected at one specific location on a specific date, it will not tell you when a species is absent from a location. For example, when determining the number of species at a location from collections data, the results may greatly underestimate the species diversity. This type of presence-only data requires careful consideration of the uses and interpretations of the data. Student research teams generally did not recognize this limitation when originally designing their research projects, which was reflected in their research proposals. We worked with the student teams individually to understand how these limitations would affect the projects and modify their questions to take these limitations into account. Students appeared to have a clearer and more nuanced understanding of these limitations by the end of the semester, which was reflected in the final research reports.

Student teams also developed their research flexibility and collaborative skills throughout the semester. It is not unusual for research projects to shift in direction or methods mid-way through the experimental process due to unpredictability in the data collection process. This was a new experience for most students and we found that they tended to resist any changes in their projects after the initial research questions were established. However, changes to the projects were necessary for student success as we discovered that some projects were too ambitious for one semester and for others the data needed simply was not available. Over the semester, as the reasons for the necessary changes became clearer to the students, we observed increased flexibility in how students thought about their experiments. Initially, the experiments were treated as static and unchanging, but our students gradually started to perceive the scientific method as a flexible and resilient process. Students also engaged more directly with the teaching team in shaping the changes to the projects. When we started the discussion with the students about project modifications, the students indicated they felt the changes were being imposed on them by the teaching team. We worked on shifting those conversations to dialogues, encouraging interaction and incorporating student ideas into the changes. By the end of the semester, the student teams had shifted from expecting us to tell them what to do and were working collaboratively with us in joint decision making.

Student Perspective

In spring 2018, we enrolled in BIOL388 Natural History Collections, a new biology course offered at Widener University. The course had a merged lecture/laboratory format to support the development and execution of semester-long independent research projects. We collaborated with the bird and mollusk curators at the Delaware Museum of Natural History and our professor on digitized natural history collections research. We worked with specimen records on an international scale, allowing exploration of globally relevant topics such as climate change and invasive species.

We began the semester learning techniques used in digitizing museum collections such as georeferencing (i.e., converting descriptive location data to latitude and longitude), study skin measurements, and input of specimen information into databases. Learning these techniques in hands-on lab periods at the museum was useful in understanding the origins of digitized specimen data. We observed that the specimens contained in a single museum were originally collected from all over the world. This was even more apparent when georeferencing mussel specimens from the Caribbean and South America. We really enjoyed learning these techniques at the museum and wished that this part of the course could have been expanded. However, we also realized that we needed to devote a majority of the course toward developing and completing our projects. This brief introduction to the digitization of collections was fundamental in helping us develop and execute original research projects centered around ecological and evolutionary questions. Understanding the international scope of the collections changed our perspective on what was possible in undergraduate research.

Based on a brief literature review, research teams of two students created a series of original and unpublished research questions focused on bird and mollusk collections. We were surprised to find that natural history collections opened the door to questions on local, national and international scales. Each pair of students discussed their research questions in detail through small group meetings with the teaching team and an initial direction of the project was decided. We initially expected that our ideas would be brought to the table and the teaching team would tell us which project to complete, however that was not the case. We were told that our initial project ideas erred on the side of overly ambitious and more along the lines of a master's thesis. The teaching team then engaged us in a conversation to determine together how to scale back our projects. Throughout the process, we still felt that we had a major say in the overall direction of our projects. We felt a greater sense of ownership of our projects than previously experienced in other project-based courses due to our ability to guide the direction of our research. We found that the professor provided more direction on course requirements and the curators helped with collections specific questions, but both the professor and the curators provided us with new ideas and motivation. The insights of the teaching team allowed us to determine what ideas might be useful and viable, and which ideas might not be reasonable within the scope of the course.

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Once our projects were scaled back for a first time, we began exploring the datasets that would be necessary to answer our research questions. We sorted and cleaned our dataset downloads using skills that were learned through a module completed during the first few weeks of the course. Completion of this module allowed us to expedite the data cleaning process that otherwise would have taken a considerable amount of time. Once the data was cleaned, we found that many of our cleaned and reorganized datasets were not useable because of missing information. Additionally, it became apparent that some projects were simply too large to complete within a single semester. Many of us felt uneasy and disconcerted at this point because we had not experienced this level of uncertainty part way through a course project. However, the teaching team did not simply take over the project but continued to let us decide where our project would head next, stepping in when necessary to guide the process. With the teaching team's help, we were able to further modify our projects to use more reasonably sized datasets or change the focus of our projects to fit within the limits of the datasets. The process of scaling back was awkward for us at first, because it was the first time many of us had made executive decisions on our own projects. We found that it was validating to have the teaching team there to support our ideas when necessary, which helped us develop a unique relationship with them. Meetings with the teaching team seemed to shift from reporting our findings in the beginning of the semester to figuring out our next moves together toward the end of the semester. This helped us begin to see the teaching team as collaborators and helped us understand how researchers can work effectively together to make decisions. This also helped us gain confidence in voicing our opinions on what future steps should entail. It was useful to see that similar thought processes occurred within the teaching team regardless of their employment at a university or a museum, which validated that critical thinking is a universal property among working professionals in the scientific community.

After we scaled back and refocused our projects, we wrote research proposals highlighting background research and a proposed plan of action to complete our projects. Submission of this proposal allowed us to receive feedback on not just our projects but also on our individual writing and critical thinking skills and served as additional validation that our projects were headed in a viable direction. Additionally, the proposal allowed the class to inform the teaching team of anything we might need outside of the dataset to complete our projects, such as GIS software to map specimen locations or preserved bird study skins from different institutions. We found that knowledge and application of ArcGIS software was a key skill in almost all of the class projects. Luckily, two students and the professor were learning ArcGIS either independently or as part of a class, so there were no major problems in mapping the specimen records across the student research teams. Additionally, the presence of the curators created the opportunity for us to borrow study skins necessary for our projects from other institutions, such as the University of Michigan Museum of Zoology and the University of California Museum of Vertebrate Zoology. Song Sparrow study skins from Canada and the United States were used for body and beak measurements. These measurements were combined with subspecies distributions from the digitized collections to determine if climate affects bird size and beak shape in the Pacific Northwest. Borrowing study skins from different institutions reinforced our global perspective of natural history collections through the international connectivity of institutions that house these collections. This course allowed us to realize that while previous courses allowed us to study local ecosystems, the global scale of biology should not be overlooked. Through this course, we were able to reach beyond our regional ecosystems and gain experience in posing important global ecological questions. For example, one research team focusing on freshwater mussels was able to pose questions relating to how invasive species and human disturbance might affect native mussel populations, reducing diversity and driving extinctions.

Throughout the remainder of the course, the teaching team allowed us to continue working with our datasets while meeting frequently with the groups to ensure projects were going smoothly. The mentoring meetings lasted from five minutes to an hour, depending on our needs at the time. When questions arose, it was extremely useful having the specialized knowledge of the curators and general knowledge of the professor at the disposal of the student research teams. With a small class size of ten students and three teachers overseeing progress, there was plenty of time for us to ask questions, seek guidance, and talk through our projects. During instances when we were off-track, the small student-to-teacher ratio allowed for the teaching team to guide us toward finding the solution. As a predominantly undergraduate institution, there are many opportunities to work with a faculty member on independent research projects. However, a traditional apprenticeship research experience is not required to complete a bachelor’s degree. Students within the class had a wide range of research experiences, however a majority of us had at least some experience. We found that our classmates who did not have as much independent research experience were much more anxious about finishing in time amidst modifications to their projects, while those of us with more experience seemed to be more relaxed in our approaches to the projects due to our previous research experiences.

A major objective of the course was to communicate scientific findings to a broad audience. Some of the students in the class were able to participate in a regional ecology conference if their project had progressed enough. Preparation for this conference was highly stressful for those who presented because the conference was held about a month prior to the conclusion of the semester with abstracts due about a month after the beginning of the semester. However, those who presented did find that the opportunity allowed them to practice their scientific communication skills and talk to additional experts outside of the teaching team about future directions and modifications to the project. It took many hours outside of class to obtain meaningful data and prepare our presentation in time. Therefore, it might not be ideal for future students if they are juggling a rigorous course load.

We were also responsible for the completion of both a scientific paper and a museum exhibit. We found that writing and receiving feedback on our proposals in the first half of the course helped with writing the course paper, as the introduction and methods sections were very similar. The paper allowed projects to come full-circle and provided students an additional opportunity to receive feedback on their writing skills. It also allowed us an opportunity to learn about and understand some of the broader impacts of our research. The museum exhibit was designed to provide us with a chance at practicing scientific communication to a general audience. Some members of our class found this project to be especially challenging because the focus of most undergraduate courses at Widener is on developing clear scientific communication within the scope of an academic audience. Some of the students commented that they wished that more time was spent developing their displays. However, they also understood that there were time constraints to finish the course by the end of the semester.

Throughout the course, there were also numerous opportunities to convey our ideas to a general audience. We submitted weekly posts on social media, such as Twitter or Instagram, communicating about our progress in the course, what we were enjoying, or something fun that we were learning. We were also required to submit a blog post about our research to be posted on the museum's website (see http://www.delmnh.org/insider-look/). The museum display, social media posts, and blog posts were all activities that helped us realize the power of social media as a platform to communicate to readers of diverse backgrounds. For example, one research team focused on the relationship between the number of unique fish species and the number of unique freshwater mollusk species in four sample areas in a Tennessee watershed. Creating a museum display challenged us to explain a scientific finding without using specific jargon that would not be understood by a general audience.

Over the semester, we developed our independent thinking skills and increased our self-confidence as members of the global scientific community. Most upper division biology laboratory courses are taught through predetermined activities and experiments with limited room for student input. This course brought increased freedom as we were able to choose the directions of our own research projects. As a result of this increased freedom, our class was initially apprehensive about our capabilities to develop and carry out our own experiments. However, we transitioned from asking question after question about our projects out of fear of doing something incorrectly to making independent strategic decisions based on our results. This transition in confidence seemed to alter the way that we interacted with the teaching team. Towards the conclusion of the course, we were more engaged and more confident in voicing our own thoughts on where to move our projects, signifying that our class was beginning to see the teaching team more as mentors and collaborators than superior and intimidating beings. The flexibility of this course also allowed us to see that our teachers are not all-knowing and that our input in the scientific process is valuable.

Our class was pleasantly surprised at the relative ease with which natural history collections data can be accessed from anywhere in the world to answer globally-relevant questions. We found that there are certain challenges in using these collections to answer ecological questions, such as historical limitations in what specimens were collected. However, we did find these collections useful when considering questions related to threatened or endangered species that may have certain restrictions in studying them or toward studying long-term changes in how species are distributed across the globe. A general consensus within our class prior to taking this course was that biological research needs to have either a field or wet lab component. This course showed many of us that biological questions can at least begin to be answered from the comfort of our dorm rooms or houses using databases of digitized specimens collected all around the world with simple access to the internet. Digitization of natural collections really opens the door to allowing anyone with an internet connection access to global data that they can use to answer questions related to what is going on in the natural world.

Conclusions

We found that digitized natural history collections research was effective in increasing student engagement with biological questions that crossed international borders. Research projects on globally relevant topics such as climate change became more accessible to undergraduate students. By opening up new avenues of undergraduate research, access to global natural history datasets gave our students more research project options, and therefore more control of the directions of their projects. This increased their engagement and sense of ownership of their projects. Through frequent discussions with the student research teams about their progress throughout the semester, the teaching team worked to maintain student leadership on the projects, with the teachers acting as collaborators and sounding boards throughout the process. As a result, we experienced increased student engagement in research discussions, more willingness from students to approach the teaching team for assistance, and a higher level of student independence. Additionally, the inclusion of museum curators on the teaching team allowed the students to engage with a scientific community outside of the university, broadening student perspectives on the diversity of biological research communities.

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This course also provided an opportunity for us to grow as mentors. It was novel and occasionally disconcerting for all when the teaching team yielded primary decision-making on the research projects to the students. Our willingness to let students lead was rewarded, however, when the students rose to the challenge with increased independence and collaborative decision making with the teaching team. We also have a better understanding of the areas where students tended to struggle and can better prepare students to expect these challenges and provide more effective mentoring. For future classes, we will develop additional technical resources including guidance on scientific name usage, mapping programs, and resource lists of appropriate environmental variables. Overall, we were impressed with the progress all students made as they moved down the pathway from students to scientific collaborators.

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